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# Cultivar loss and conservation of genetic resources of the phureja potato (*Solanum phureja* L., Phureja Group) in Peru

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**Abstract:** *Solanum tuberosum* L. Phureja Group, known in Peru as 'phureja potato' or 'chaucha potato' and as 'criolla' in Colombia, is characterized by its earliness and the absence of dormancy in the tubers. It stands out for its nutritional value and its contribution to food security. However, it faces a high risk of disappearance in Peru. This study assessed its current status by collecting historical data, *ex situ* and *in situ* conservation analyses, and genetic erosion studies in local communities. Historical information suggests that phureja was relevant and abundant in the past. Currently, e*x situ* collections include 69 accessions, of which the International Potato Center conserves a significant portion. As for *in situ* conservation, 116 accessions have been identified. However, since 1992, genetic erosion has been documented in six departments of Peru. The main causes include: lack of time for continuous cultivation, prioritization of dairy farming, low seed quality, preference for more commercial modern or traditional cultivars, and the expansion of mining projects. The critical situation of the phureja potato requires urgent measures to collect new information and evaluate the remaining genetic variability. This assessment is essential to develop conservation and sustainability strategies to ensure its survival and its contribution to Peru's food and cultural well-being.

**Keywords:** Genetic erosion; potato diploid, *Solanum phureja*, yellow potato, chaucha

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## Introduction

The understanding of global biodiversity remains limited, reaching only 20% of species. Especially in the centres of origin of cultivated plants, there are gaps in knowledge about how farmers preserve local cultivars. This, in turn, hinders the implementation of methodologies that could favour conservation, such as establishing baselines, conducting monitoring and collecting evidence on cultivar dynamics (losses and additions) and the likely genetic erosion involved (De Carvalho *et al*, 2016; Dawson *et al*, 2023).

Genetic erosion – the loss of crop genetic diversity in specific contexts of time and space – is a persistent concern in the agri-food field. Its dynamics, triggers, measurement methods and magnitude of losses are still not fully understood (van de Wouw *et al*, 2009; Khoury *et al*, 2022). This problem is especially critical

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in key crops such as potato, which is key to food security, nutrition and sustainability of global agri-food systems. The reduction of the crop's genetic diversity limits its ability to adapt to environmental changes and phytosanitary challenges, threatening both agricultural productivity and the livelihoods of dependent communities (Burgos *et al*, 2020; Devaux *et al*, 2020).

The phureja potato is classified under the International Code of Botanical Nomenclature (ICBN) as the species *Solanum phureja* (Juz. & Buk.). Its taxonomic key indicators are: corolla lobes wider than half the petal length, short acuminata, leaves somewhat glossy, less densely pubescent (Ochoa, 2001). On the other hand, according to the International Code of Nomenclature for Cultivated Plants (ICNCP), this potato is located within the Phureja Group, as *Solanum tuberosum* L. Phureja Group, and its taxonomic key indicates that tubers sprouted at harvest (Huamán and Spooner, 2002). Its most notable features are its rapid maturation, from three to four months, and the lack of a resting period for its tubers (Ochoa, 2001; Huamán and Spooner, 2002).

The phureja potato stands out for its high nutritional and culinary value, and its richness in secondary metabolites with antioxidant properties. It is an important source of essential minerals such as potassium, iron and zinc, which reinforces its nutritional value (Cerón-Lasso *et al*, 2018; Beltrán-Penagos *et al*, 2020; Peña *et al*, 2021). Its tolerance to adverse conditions, such as poor soils and high altitudes, makes it a resilient option in the face of climate change. It also has great potential in the produce industry. Its role in genetic improvement is crucial, contributing valuable genes to develop more resistant and sustainable varieties (Gabriel and Franco, 2013; Ñústez and Rodríguez, 2020). It has been considered as one of the world's 50 foods of the future (Ñústez, 2021).

Despite its importance, the phureja potato has received little conservation attention in Peru. This situation is evident in the south and centre of the country, where several studies conducted in the last three decades (Zimmerer, 1991; De Haan and Thiele, 2004; CIP and FEDECH, 2006; Plasencia *et al*, 2018) have documented significant losses. Similarly, a report focusing on northern Peru (Seminario and Zarpán, 2011) suggest that this potato could be at risk of disappearing. Based on this background, the objective of this research was to gather evidence to evaluate its relative importance in the past and to analyze the loss of cultivars that occurred in the last decades in Peru.

## Materials and methods

### Records of the presence, importance and relative abundance of the phureja potato in Peru

Historical sources on ancient Peru were used, including the works of Varcárcel (1985), the report by J.B. Martinet at the end of the 19th century (Martinet, 1977), and the works of Herrera (1921) and Vargas (1936, 1946, 1955), among others. Historical information was also gathered on one of the pioneers in potato conservation and genetic improvement in the Paucartambo region (Cusco). This is Mr. Yabar, recognized for his valuable work between the 1930s and 1945, during which time he promoted early practices of conservation and selection of local potato cultivars (Yabar-Villagarcía, 2004). Another key source was the database of Ochoa (2003), which contains information on passport data from native potato collections carried out in Peru between 1947 and 1997.

### Information about *ex situ* conservation of the phureja potato in Peru

In 2020, a contact was established with personnel responsible for the potato collections of the experimental stations at the National Institute for Agrarian Innovation (INIA), the institution in charge of preserving the genetic resources of cultivated plants in Peru, located in the localities of Puno, Cusco, Junín, Ayacucho and Cajamarca. During this period, detailed information was collected on the number of accessions (units of genetic material) of phureja potatoes conserved in each station. This work allowed us to understand the practices and criteria applied for the conservation of this germplasm in different regions of the country. In addition, in 2023, the database of the International Potato Center (CIP) was accessed to obtain the number of phureja potato entries and those corresponding to Peru.

In Cusco, access was granted to the germplasm database managed by a group of communities there known as the 'Parque de la Papa', managed by the NGO Andes del Cusco Association. This database is an exhaustive register of native potato cultivars, including phureja varieties, conserved *ex situ*. Among these materials are samples repatriated from CIP, preserved in collaboration with local communities associated with the park. In addition, information was collected from the Regional Center for Andean Biodiversity Research (CRIBA) of the Universidad Nacional de San Antonio Abad del Cusco (UNSAAC), specifically on the number of native potato and phureja varieties stored in its germplasm bank.

In the city of Paucartambo, the Salcedo Rojas family coordinates the activities of the Paucartambo Conservationists Association. After an interview with two family members, we were able to access (for systematization and analysis) the database on native potatoes maintained by 30 conservationists from the districts of Paucartambo, Challabamba, Colquepata, and Huancarani. In addition, an interview was conducted with Julio Hancco, an outstanding conservationist from the community of Pampacorral, located in the province of Lares, who is widely recognized for his work in the conservation of agricultural biodiversity.

In the Cajamarca region, interviews were conducted in 2011 and 2021 with 20 potato conservation farmers

in the provinces of Cajamarca, Celendín, Hualgayoc and San Marcos, previously identified in a study by Seminario and Zarpán (2011). The objective of these interviews was to determine the number of germplasm entries they maintain and to analyze the socioeconomic factors that affect their conservation work.

## Information about *in situ* conservation of the phureja potato in Peru

The catalogues of native potatoes produced in Peru during the last two decades were compiled and analyzed. Those catalogues that specify the species to which the accessions belong or that, at least, record the duration of tuber dormancy were included. Although these documents do not provide direct information on cultivar erosion, the presence or absence of phureja potatoes in these collections is considered a relevant indicator of the level of conservation of this group on farmers' farms.

In Cajamarca region, information was collected on phureja potato collections carried out since 2005 in several provinces of this region. These data provided a comprehensive overview of the conservation efforts of potato cultivars and varieties by the communities. In addition, these activities made it possible to explore the challenges, strategies and traditional knowledge associated with *in situ* conservation, especially highlighting the crucial role of communities in the preservation of the genetic diversity of the phureja potato. Also in 2021, in the provinces of Chota and Cutervo, interviews were conducted with 45 potato farmers and information was collected on the phureja cultivars planted in the previous season and the varieties lost in the last two to three decades (Figure 1). In the locality of Waqanqa, located in the district of Paucartambo, Cusco, direct observation was carried out between 16 and 19 February 2020 with the objective of identifying potato cultivars. In addition, 16 farmers from the districts of Paucartambo and Challabamba, who participated in the XIX Agricultural Fair, held on 11-12 September 2023, were interviewed (Figure 1).

## Empirical evidence on genetic erosion of the phureja potato in Peru

An exhaustive literature search for research related to the genetic erosion of the phureja potato was carried out, covering articles and other scientific publications produced between 1980 and 2023 that document the loss of native potato germplasm in Peru. For this purpose, physical libraries and bibliographic databases of wide coverage, such as Google Scholar, SciELO, Web of Science and Scopus, were consulted in order to gather and analyze information on this topic.

# Results

## Presence, importance and relative abundance of the phureja potato in Peru

According to information gathered from existing literature, catalogues, germplasm banks and farmers' knowledge, the phureja potato is grown or present in 11 of Peru's 25 regions. These regions are mainly located in the Andean zone, at altitudes ranging from 2,000 to 3,500 meters above sea level (Figure 1).

Since ancient times, the phureja potato has been an essential source of food and a key component in the food security of Andean communities (Forbes *et al*, 2020). In ancient Peru, five types of potato were identified, classified in Quechua language according to their morphological characteristics and agroecological adaptations: hatun papa (large potato), chaucha [= phureja] papa (early maturing potato), maguay papa (early planting potato), capo papa (possibly qjapo papa, associated with elevated areas and dark soils) and chiri papa (potato cultivated in cold regions) (Varcárcel, 1985).

Herrera (1921) described the diversity and quality of potatoes in Paucartambo (Cusco), classifying non-bitter potatoes into four groups. Within the group of elongated potatoes, he included the chaucha or phureja potato, characterized by its rapid growth, watery tubers and reddish buds, although there were also varieties with round tubers and white buds. These potatoes have a cultivation cycle of approximately three months. Vargas (1936) also highlighted the importance of phureja potatoes in Paucartambo. These, known locally as papa nueva, mosoc papa or misca mahuay, are sown early and are used both for immediate consumption and starch extraction. In addition, Vargas (1946) gathered a collection of 774 potato samples mainly from Puno, Apurímac and Cusco, of which 79% corresponded to *Solanum andigenum* and 10% to *Solanum stenotomum*. Later, in *Las Papas Sudperuanas, Parte II,* Vargas identified four clones of chaucha potatoes (1206, 1207, 1208 and 1209) belonging to *S. stenotomum*, and one clone (549) classified within *S. andigenum* (Vargas, 1946).

Luis Á. Yabar Ordóñez (1886-1965), a horticulturist originally from Paucartambo, stood out as a pioneer in the conservation of native potatoes in Peru during the period from 1930 to 1945. Yabar compiled and maintained a valuable collection of approximately 250 native potato cultivars, including the churumpis, chauchas or phurejas, miskillas, thumillas, tokolos and phasñachas groups (Yabar-Villagarcía, 2004). His work was widely recognized by specialists in the study of this tuber. In 1944, J. G. Hawkes acknowledged his contribution by naming a species in his honour: *S. yabari*, which included two varieties, *S. yabari* var. *pepino* and *S. yabari* var. *cuzcoense*. These species were later reclassified as part of *S. stenotomum* (Ochoa, 1999; Watanabe *et al*, 2008).

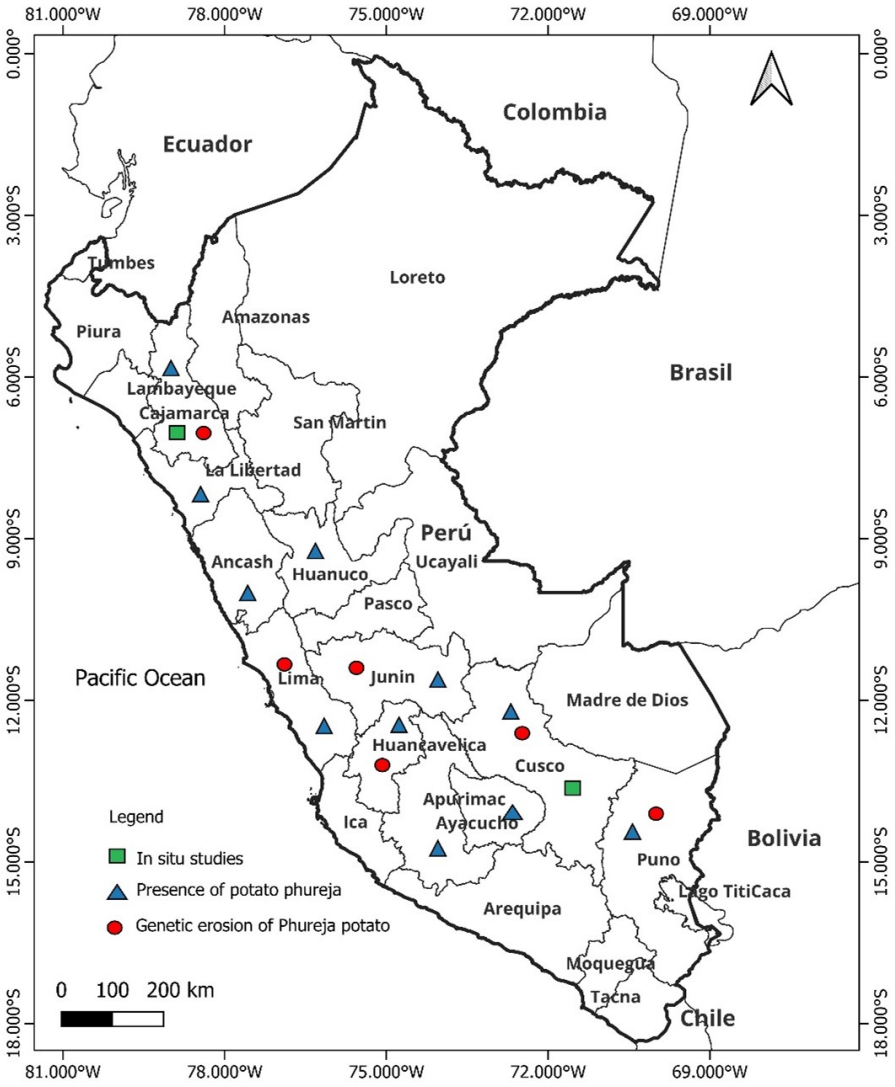


**Figure 1.** Map of the 25 regions of Peru showing the location of *in situ* studies, as well as the presence and erosion of the phureja potato.

A report from the mid-1940s noted that commercial potato varieties in Peru included chata blanca, chata rosada, chata negra, chata negra, amarilla, shitu, mauna and chaucha (Derteano, 1944). In the 1960s, C. Ochoa documented the presence of specimens of chaucha blanca, chaucha colorada and chaucha negra in the province of Sandia, Puno (Ochoa, 1964). Subsequently, Soukup (1970) described the chaucha potato or phureja potato as an early maturing variety characterized by its rapid cooking, even at the first boiling.

In Cajamarca, Iberico (1981) noted that the chaucha potato is distinguished by its characteristic colour, similar to that of egg yolk, as well as its extremely smooth texture and pleasant flavour. This tuber is commonly consumed parboiled and with skin. Leiva *et al* (1990) documented its use in traditional medicine, specifically to relieve headaches. In this context, it is applied sliced with salt as a poultice on the temples, or ground in combination with olluco (*Ullucus tuberosus*), white corn (*Zea mays*), salt and vinegar for therapeutic purposes.

C. Ochoa, noted for his extensive potato collections between 1947 and 1997, collected a total of 322 phureja potato samples from 15 departments of Peru. These samples were organized according to their relative abundance as follows: Amazonas (140), Puno (52), Cajamarca (30), Ayacucho (28), Piura (16), Huánuco (12), Junín (11), Lima (11), La Libertad (6), Apurímac (4), Huancavelica (4), Ancash (2), Cusco (2), Pasco (1) and Lambayeque (1). These data reflect the distribution and prevalence of the phureja potato during this period. However, Ochoa (2003) noted that these samples were preserved only as herbarium specimens in various museums in Peru and other parts of the world.

## *Ex situ* conservation of the phureja potato in Peru

In Peru, 6,295 native potato accessions have been identified in eight databases of working collections,

including a university, a civil association and four experimental stations of INIA located in the Sierra (Table 1). Of these, only 0.3% correspond to the Phureja Group, which shows its minimal representation, even in the three main collections of the Cusco region, where its presence is insignificant. At the international level, CIP, which houses the world collection of potato germplasm, conserves only nine accessions of *Solanum tuberosum* L. Phureja Group from Peru, out of a total of 181 accessions of this species, most of which originate from Colombia and Ecuador (CIP, 2023).

The database of the Paucartambo Native Potato Growers' Association initially registered 2,500 cultivars. Each farmer maintains between 38 and 140 cultivars on average. Within this group, only two cultivars belong to the Phureja Group: Puka q'achirma and K'ello q'achirma. Both varieties are kept by a single farmer in the locality of Challabamba.

Julio Hancco, a well-known conservationist from Pampacorral, Cusco, reported that he had a collection of 350 potato cultivars, although none belong to the Phureja Group. He also reported having limited knowledge of this category of potato. Consistently, the analysis of the catalogue of a lot composed of 115 documented cultivars from his collection did not show the presence of cultivars of the Phureja Group either (Hancco *et al*, 2008).

In 2010, 20 conservationists of the Cajamarca Potato Producers Association dedicated to the conservation of native potatoes, including cultivars of the Phureja or Chaucha Group, were identified in Cajamarca. Of these, 17 maintained between 1 and 12 cultivars of the Phureja Group (Table 2). By 2021, the number of active conservationists decreased to 18, of which only 11 preserved between 1 and 10 cultivars of this group (Table 2). The total reduction in the number of native potato accessions in general and of the Phureja Group in particular was 50% and 52%, respectively.

The decrease in cultivars observed in 2021, together with the reduction in the number of active conservationists, is partly attributed to the advanced age of the latter, with an average age of 62 years, which limited their ability to continue conservation work. In addition, there were significant changes in the main economic activities of the conservationists: five focused primarily on livestock, four replaced agriculture with other occupations (such as carpentry, salaried work or temporary migration), three moved to urban areas while maintaining only partial agricultural activities, and one completely abandoned his activities due to chronic illness. Together, the remaining small collections total 35 accessions conserved *ex situ* in Cajamarca (Table 2).

## *In situ* conservation of the phureja potato in Peru

Between 2006 and 2023, 27 regional catalogues of native potato were prepared, of which 19 met the established inclusion criteria. A total of 2,102 native potato accessions were identified in these catalogues, of which 4.3% correspond to the Phureja group (Table 3). Among the most outstanding catalogues are: Cuyo Cuyo (Puno), in the south, with 13 cultivars of the Phureja group (Wildlife Conservation Society , 2022); Huánuco, in the centre of the country, with 17 cultivars of phureja potato (Egúsquiza, 2015); and Cajamarca, in the north, which records 43 cultivars of Phureja. The Cajamarca collection was morphologically characterized, highlighting the first 15 accessions collected in three districts of Hualgayoc, which achieved a successful harvest (Figure 2) (Seminario and Zarpán, 2011; Seminario *et al*, 2019). In addition, in 2021, in the Cajamarca provinces of Chota and Cutervo, 24 cultivars of Phureja planted in local farms during the last agricultural seasons were identified, and identified by their traditional names.

The exploration conducted in the community of Waqanqa (Paucartambo, Cusco) indicated that potato cultivation has been reduced in area and cultivars. No phureja potato cultivars were found. On the contrary, corn, apple and pasture crops stood out. Also, 16 farmers participating in the XIX Agricultural Fair of Paucartambo (11-12 September 2023), who were interviewed, indicated that they maintained between 2 to 250 varieties of native potato, and nine of them planted one to two chaucha cultivars (puka chaucha or k'ello chaucha). They mentioned that these potatoes had been lost due to lack of time to attend to the crop, because of their rapid sprouting and the scarcity of seed.

## Empirical evidence of genetic erosion of the phureja potato in Peru

Genetic erosion in potatoes of the Phureja Group had its first documented evidence in Waqanqa, the largest community in the Mapacho river valley, in Paucartambo. This group of potatoes, traditionally cultivated in the region, showed a progressive disappearance since the 1960s, being reduced to only four or five varieties in 1987. Factors such as labour shortages, migration to urban areas and low local appreciation of these cultivars led to their replacement by improved varieties (Zimmerer, 1991, 1992).

Canahua *et al* (2002) conducted a study in regions with extensive areas of potato and quinoa cultivation in six provinces of Puno. The results indicated that the cultivation of potatoes of the Phureja Group is restricted to small areas in the localities of Moho, Yunguyo and Viquechico. In addition, it was concluded that these cultivars are in danger of disappearing due to their low yields, despite being valued for their short maturity cycle and remarkable regeneration capacity.

De Haan and Thiele (2004) documented a decline in the frequency of cultivation of cultivars of the Phureja Group in the district of Yauyos, Lima. This phenomenon was attributed to factors such as limited seed availability, low capacity for germplasm exchange, labour shortages, and farmers' increasing preference for more commercial cultivars such as 'Huayro' and 'Peruanita'.

**Table 1.** Accessions of native potato and phureja potato, maintained *ex situ* in regional genebanks in Peru, 2020. [a], 778 collected within the Potato Park, 410 repatriated from CIP and 150 obtained through seed exchange; [b], Collected in Puno. N/A: Information not available.

| Location | Native potato | Phureja potato | Source | Institutions |
|---|---|---|---|---|
| Cusco | 2,500 | 12 | L. Lizárraga, interview, 18 Feb 2020 | RCABR -UNSAAC |
| Pisac, Cusco | 1,345[a] | N/A | A. Argumedo, interview, 15 Feb 2020 | Andes Association, Potato Park |
| Cusco | 1,300 | 5[b] | L. Palomino, interview, 20 Apr 2020 | INIA, Andenes |
| Ayacucho | 400 | N/A | M. Morote, interview, 2 May 2020 | INIA, Canán |
| Junín | 300 | 3 | N. Zúñiga, interview, 2 Mar 2020 | INIA, Santa Ana |
| Puno | 450 | 1 | R. Cahuana, interview, 15 May 2020 | INIA, Illpa |
| Cajamarca | N/A | N/A | H. Roncal, interview, 25 May 2020 | INIA, Baños del Inca |
| **Total** | **6,295** | **21** | | |

**Table 2.** Native potato accessions (total and phurejas) maintained by conservationist farmers in Cajamarca in 2010 and 2021. Source: Interviews conducted in 2010 (Seminario and Zarpán, 2011) and 2021, respectively. N/A: not available.

| Conservationist name | Province/district | Age in 2021 | 2010 | | 2021 | |
|---|---|---|---|---|---|---|
| | | | Total acc. | Phureja acc. | Total acc. | Phureja acc. |
| Juan Huaccha | San Marcos/ Pedro Gálvez | 62 | 200 | 2 | 90 | 2 |
| Santos Abanto | San Marcos/Gregorio Pita | 61 | 90 | 3 | 30 | 1 |
| Pedro I. Abanto | San Marcos/Pedro Gálvez | 49 | 45 | 3 | 25 | 0 |
| Orestes Dávila | San Marcos/ José Sabogal | 65 | 40 | 1 | 20 | 1 |
| Termópilo Arévalo | Celendín/Sorochuco | 59 | 90 | 4 | 100 | 10 |
| Sergio Rodríguez | Celendín/Sorochuco | 65 | 82 | N/A | 30 | 3 |
| Armando Vergara | Celendín/Huazmín | 54 | 100 | 10 | N/A | N/A |
| Segundo D. Gil | Celendín/Huazmín | 66 | 83 | 12 | 50 | 5 |
| Idelso Garay | Celendín/Huazmín | 71 | 65 | 2 | 80 | 0 |
| Alindor Díaz | Cajamarca/ La Encañada | 74 | 45 | 3 | 15 | 3 |
| Miguel Riquelme | Cajamarca/La Encañada | 73 | 45 | 4 | 50 | 2 |
| Gumercindo Zelada | Cajamarca/Encañada | 55 | 45 | 4 | 10 | 2 |
| José I. Ayay Valdez | Cajamarca/ Cajamarca | 70 | 75 | 0 | 70 | 1 |
| Germán Sangay | Cajamarca/ Encañada | 58 | 35 | 3 | 60 | 0 |
| Emilio Huamán | Cajamarca/Namora | 48 | 295 | 4 | 0 | 0 |
| Abel Marín Ríos | Cajamarca/Namora | 61 | 180 | 1 | 15 | 0 |
| Juan E. Mendoza | Hualgayoc/Bambamarca | 50 | 15 | 6 | 20 | 5 |
| José Telmo Cabrera | San Marcos/Gregorio Pita | 65 | 80 | 3 | 70 | 0 |
| Luis Cabrera Ocas | San Marcos/Gregorio Pita | 70 | 180 | 2 | 160 | 0 |
| Wilson Pastor Marín | San Marcos/Gregorio Pita | 67 | 50 | 0 | 20 | 0 |
| **Total** | | | **1,840** | **67** | **915** | **35** |

CIP and FEDECH (2006), together with De Haan *et al* (2010), conducted a study in Huancavelica on two potato groups, identifying the presence of 144 and 557 cultivars from four provinces and eight communities, but found no cultivars belonging to the Phureja Group. This absence was attributed to factors such as seed loss, temporary migration of inhabitants, substitution by modern cultivars and the lack of dormancy characteristic of this species. However, Brush *et al* (1981) documented the existence of a single cultivar of *Solanum phureja* called 'Pujuya' in the community of Aymará, Tayacaja district, Huancavelica, known for its frost resistance and also cultivated by farmers in nearby regions such as Chongos Alto, in Huancayo, Junín.

The Ministry of Agriculture conducted research in the southeastern Junín department on native potatoes, identifying that it was currently difficult to find cultivars of the Phureja Group (MINAGRI, Grupo Yanapai, INIA and CIP, 2017). Similarly, Plasencia *et al* (2018), in a study on the diversity of native potatoes in Challabamba (Paucartambo) and Quillcas (Junín), reported the presence of all the species studied, except *S. tuberosum* L. Phureja Group, although the causes of its absence were not determined.

Seminario and Zarpán (2011) and Seminario *et al* (2019) estimated a 17% reduction in cultivars of the Phureja Group in five provinces of Cajamarca over the previous two decades. The main causes of this decline include the lack of time to attend to the crop, due to its short sowing and harvesting cycles; the preference of local communities for livestock activities rather than agriculture; the low quality of seed, which in many cases

**Table 3.** Number of potato phureja cultivars in 19 Peruvian native potato catalogues in 2023.

| Regions/Communities | Total cultivars | Phureja potato | Source |
|---|---|---|---|
| Huancavelica/ Huayta Corral, Tupac Amaru, Villa Hermosa, Pucara, Dos de Mayo | 144 | 0 | CIP and FEDECH (2006) |
| Cusco/ Huama, Huarqui, Poques, Patacancha, Willoc, Tauca | 260 | 0 | Cosio (2006) |
| Cusco/ Palccoyo, Acco Acco Phalla y Quisini (district of Sicuani) | 141 | 0 | Gutiérrez and Valencia (2010) |
| Cajamarca/ Chota and Lajas | 23 | 5 | INCAP Jorge Basadre (nd) |
| Cajamarca/ Three communities of Shitamalca | 24 | 1 | Programa Bioandes (nd) |
| Cajamarca | 28 | 5 | Cabrera and Pando (2011) |
| Cajamarca/22 communities | 43 | 43 | Seminario *et al* (2019) |
| Puno | 86 | 0 | Muñoz and Estaña (2012) |
| Cusco/ Quescay, Kcallacancha, Sipascancha Alta, Miscahuara | 30 | 4 | Revilla (2014) |
| Apurímac y Huancavelica. | 24 | 0 | Fonseca *et al* (2014) |
| La Libertad/ San Juan, La Soledad, Canucubamba, Macullida, Las Colpas, Arcopampa y Chugay | 129 | 1 | CIP, Asociación Pataz., and INIA (2015) |
| Huánuco/ 35 communities | 296 | 17 | Egúsquiza (2015) |
| Huánuco, Junín, Huancavelica, Ayacucho, Apurimac | 12 | 0 | Riveros and Peralta (2015) |
| Junín/ Seven communities and 14 families in the southeastern part of the department | 146 | 1 | MINAGRI, Grupo Yanapai, INIA and CIP (2017) |
| Apurímac/ Huayana y Pomacochas | 119 | 0 | PRODERIN (2018) |
| Apurimac, Cusco y Puno/113 communities of Apurimac, 58 de Cusco and 8 of Puno | 200 | 0 | Roldan *et al* (2019) |
| Huancavelica/ Castillapata, Paltamachay, Huachhua, Paccho Molinos, Santa Rosa de Pacchaccla y Pumaranra | 184 | 0 | CIP, Grupo Yanapai, Gobierno Regional de Huancavelica and AGUAPAN (2021) |
| Puno/ Cuyocuyo | 91 | 13 | Wildlife Conservation Society (2022) |
| La Libertad/ La Victoria | 122 | 0 | Asociación-Pataz, CIP, INIA and AGUAPAN (2023) |
| **Total** | **2,102** | **90** | |

was depleted and with poor yields; the expansion of mining projects in the region; the trend towards the cultivation of modern varieties and more commercial native cultivars; labour shortages, caused by emigration and employment in non-agricultural activities; and the limited availability of seed for crop regeneration.

In 2021, a field study in the provinces of Chota and Cutervo (Cajamarca) revealed the loss of eight Phureja potato cultivars in the last two decades, reducing the total recorded from 32 to 24 (Table 2). The missing cultivars included Huevo de perdiz, Baya, Cemelina, Rosada, Morada, Negra, Chilopa and Amapola. The main causes identified are the rapid growth cycle of this group, which makes its management difficult; the preference for modern cultivars that are more competitive in the market; the prioritization of livestock; and the low quality of the available seeds, known as 'tired seeds'. Currently, the remaining germplasm of Phureja potato in Cajamarca comprises 67 cultivars, of which 43 have been morphologically characterized in five provinces, while 24 are only nominally registered in Chota and Cutervo. It is essential to extend studies to other provinces to evaluate diversity and promote its conservation.

## Discussion

Historical evidence (Vargas, 1936, 1946, 1955; Herrera, 1921; Varcárcel, 1985) and Ochoa (2003) collections in 15 of the 19 departments where potatoes are grown in Peru highlight the historical relevance of the Phureja potato. Its distinctive characteristics, such as the absence of dormancy, precocity and adaptation to early harvests, underline its agricultural importance. However, it is necessary to thoroughly review the historical data (van de Wouw *et al*, 2009) and to explore again the sites visited by Ochoa to confirm the persistence of Phureja in these regions. This will allow updating knowledge about its persistence, as well as its agricultural and cultural value in the current context.

*Ex situ* collections are essential to preserve genetic diversity and prevent its loss, acting as a vital complement to *in situ* conservation. Both strategies

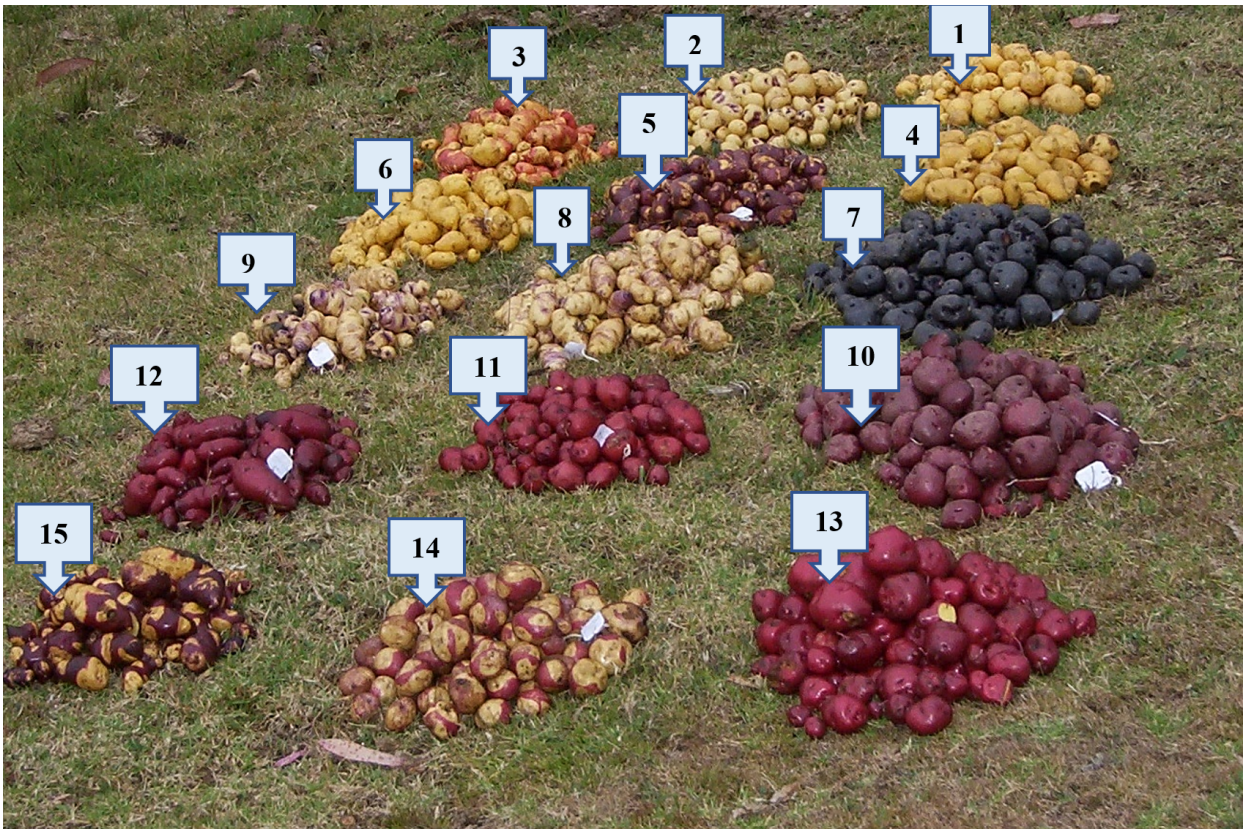


**Figure 2.** Phureja or chaucha potato cultivars harvested in the province of Hualgayoc, Cajamarca, northern Peru, in 2005: 1.Chaucha (Ch). Chachapoyana, 2. Ch. Blanca, 3. Ch. Huagalina, 4. Ch. Porpora, 5. Ch. Conda, 6. Ch. Amarilla, 7. Ch. Negra, 8. Ch. Colombiana, 9. Ch. Colombina negra, 10. Ch. Montañera, 11. Ch. Shoga, 12. Ch. Pabla, 13. Ch. Pimpinela, 14. Ch. Blanca peruanita, 15. Ch. Clavelina. In northern Peru, the names of phureja potato cultivars are usually composed of two elements: a primary common name, such as chaucha, and a secondary name which, in many cases, may coincide with the names of cultivars belonging to other potato groups. For example, Ch. Huagalina, whose secondary names may be related to specific physical characteristics.

are integrated to ensure the availability of these resources for future generations (Priyanka *et al*, 2021). A key advantage of *ex situ* collections is their accessibility to researchers and users, allowing their use in training, genetic improvement, research and repatriation to source communities (Fu, 2017; Ellis *et al*, 2020; Nagel *et al*, 2022). However, in Peru, *ex situ* germplasm of Phureja potato is limited, with only 65 accessions, distributed among state institutions (21), conservationists (35) and CIP (9). The reasons for this scarcity of *ex situ* samples need to be investigated. This could be due to the scarcity of these materials on farms or to a lack of interest among researchers and conservationists, due to the difficulty of preserving them because of their lack of dormancy.

This germplasm does not represent a significant complement for *in situ* conservation, nor does it constitute a solid base for the repatriation of cultivars (Joshi *et al*, 2020; Lüttringhaus *et al*, 2021). The most prominent collections of Phureja potato in the Andes are in Colombia: that of Nariño and northern Ecuador, together with the Colombian central collection, which together conserve 348 accessions (Rodríguez, 2010; Lasso *et al*, 2018). Surprisingly, the United States Potato Germplasm Bank (USPG) houses 144 Phureja potato accessions, all unique and without duplicates (Río and Bamberg, 2021). This highlights the importance of integrating international efforts for the conservation and study of this valuable genetic diversity.

Phureja potato cultivars maintained by conservationists or potato guardians in Cusco are scarce, while in Cajamarca they have experienced a drastic reduction of 48% between 2010 and 2021. Furthermore, the socioeconomic conditions of the 20 conservationists studied in Cajamarca are not favourable to guarantee efficient conservation. This evidences the need to fill a critical gap through studies on *in situ* conservation of phureja potatoes in other unexplored regions and to delve deeper into conservation dynamics in Cusco and Cajamarca. Addressing these areas will allow a more comprehensive understanding of the strategies needed to preserve this valuable genetic diversity in the context of the Peruvian Andes. The use of tools such as the four- or five-cell methodology offers an efficient way to obtain this information in a short period (Rana *et al*, 2006; Padulosi and Dulloo, 2012).

For *in situ* conservation, information from catalogues on native potatoes and specific reports in Cajamarca and Cusco were used. However, these catalogues present high variability in their content, influenced by the approach, purposes and descriptors used in their elaboration. Despite these differences, they proved to be

a valuable resource for the objectives of this research, as they provided an approximate view of the materials found *in situ*. Although they reflect information from a specific time, these documents also record cultural aspects and traditional knowledge, highlighting the work of potato conservationists. In addition, they can serve as an essential baseline for ongoing monitoring and evaluation of genetic diversity (MINAGRI, Grupo Yanapai, INIA and CIP, 2017).

The evidence gathered in this research suggests that, in Peru, *ex situ* and *in situ* conservation strategies for phureja potato are not operating in a complementary and efficient manner (Nagel *et al*, 2022). However, the data obtained may constitute a valuable reference for monitoring cultivar conservation, a priority aspect that has received little attention in cultivars in general (Padulosi and Dulloo, 2012).

The information available on the genetic erosion of the phureja potato in Peru is limited, with research conducted in only a few communities in six potato-producing departments. However, these studies provide an indication of the situation that may be occurring at the national level. Broader regional research that addresses remaining genetic variability and its relationship to the environment is essential.

The loss of cultivars is associated with factors such as the lack of time to plant and harvest crops in short periods, reflecting migration, and the prioritization of more profitable activities, such as dairy cattle ranching. In Cajamarca, areas previously dedicated to annual crops and potatoes are now used as pasture for dairy cattle. This trend, observed since the early 2000s (Winters *et al*, 2006), has been encouraged by the presence of three large milk collection companies and 1,052 artisanal dairy plants (INDECOPI, 2023), which guarantee investment security, attractive prices and immediate income for producers.

Cultivar loss is also attributed, in part, to poor seed quality (farmers say, “it no longer yields, it’s tired”), reflecting seed degeneration due to pathogen accumulation after prolonged vegetative propagation (Forbes *et al*, 2020; Sierra *et al*, 2020). The preference for modern cultivars and some native cultivars of greater commercial acceptance, observed in Waqanqa, Yauyos, Huancavelica and Cajamarca, is also a contributing factor, although studies are required to assess their impact. In addition, mining projects, especially in Cajamarca, where 53.6% of the territory of the Sierra provinces is concessioned to 33 mining companies (GPC, 2014), affect cultivars. This includes direct effects, such as employment (40% of workers in Yanacocha are local) (Yanacocha, 2018), and indirect effects, such as land sales and migration, which weaken agricultural sustainability.

In Peru, the possible occurrence of allelic or gene erosion, defined as the loss of alleles and their combinations, and genomic erosion, which implies the complete loss of the genome, has been observed in the phureja potato (Thormann and Engels, 2015). Allelic erosion occurs mainly due to the replacement of these cultivars with modern or traditional varieties of higher commercial value. Genomic erosion, on the other hand, is manifested through genetic displacement due to the elimination of the phureja potato from cropping systems. If this process continues, the implications would be serious for the country, as it would face the definitive loss of this species (*S. tuberosum* L. Phureja Group), which would have a significant impact on agricultural biodiversity and food security.

## Conclusion

The phureja potato, is present in 11 of Peru’s 25 regions. Despite its historical relevance and former abundance, this valuable crop is now in danger of disappearing in the country. The germplasm of the phureja potato in Peru includes 90 accessions conserved *in situ*, 21 *ex situ* accessions maintained by state institutions, and 35 accessions safeguarded by farmers in the Cajamarca region. This research represents the first systematic effort to document the genetic diversity and erosion of this resource. It is crucial to complement this initial analysis with new regional data to validate its consistency and to develop a comprehensive national inventory to identify and preserve the remaining genetic variability.

The loss of genetic resources and the erosion of the phureja potato are influenced by several interrelated factors. Among them, farmers’ lack of time to attend to this crop, which requires continuous planting and harvesting, is aggravated by labour shortages due to the emigration of the most skilled members of rural families. In addition, the shift to more profitable activities, such as dairy farming, and the priority given to improved cultivars or commercial varieties displace the phureja potato. Other factors include the scarcity and poor quality of seed, and the presence of mining projects that affect cultivation areas.

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## Author contributions

JFSC: conceptualization, methodology, writing original draft, revision. LSCT: data collection, formal analysis. ASC: writing original draft, review. TMH: data collection

and curation, WS: methodology, visualization, review and editing.

## Ethics statement

The authors declare that this research did not require the approval of an ethics committee, as no clinical or experimental procedures requiring such approval were performed. However, the ethical principles applicable to research involving human subjects were strictly adhered to. Before each interview, participants were clearly informed about the objectives of the study, the voluntary nature of their participation, and their right to withdraw at any time without penalty. Informed consent was obtained orally and in language accessible to each interviewee. Each person was also given the option of authorizing the use of their name in the research. Their dignity, rights, and autonomy were respected at all times.

## Conflict of interest statement

The authors declare no known conflicts of interest, financial or personal relationships that could influence the work or materials presented in this article.

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